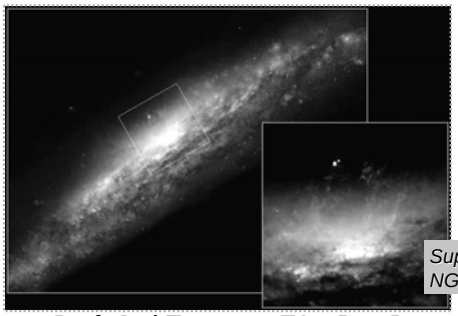
ASTR 1120: Stars & Galaxies



Superbubble NGC 3079

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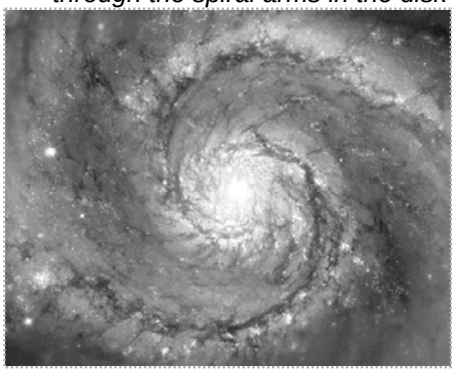
Lecture 29 Fri 18 Mar 05

zeus.colorado.edu/astr1120-toomre

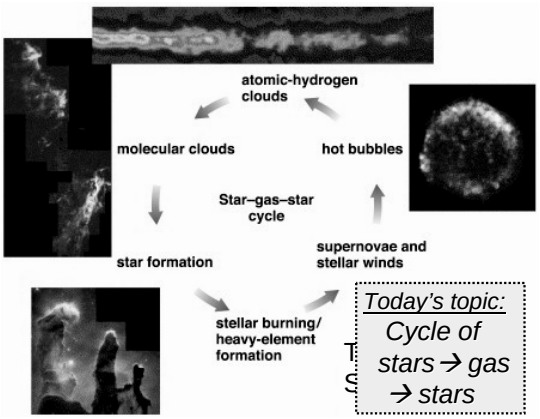
Today before Spring Break-Away

- Examine the *Star-Gas-Star Cycles* working in our galaxy disk, and its ingredients
- *Interstellar Medium (ISM)* – gas and dust, plus *super-bubbles* blown by multiple supernovae
- *Recycling* on a grand scale, and building the heavier atoms
- Complete your reading of *19.5 Mysterious Center of our Galaxy*
- *Second Mid-Term Exam* + answers still available for retrieval
- *Problem Set 7* due in class today

Crash/bang of star birth and recycling: rotating through the spiral arms in the disk



M51 Whirlpool Galaxy HST



Today's topic:
Cycle of stars → gas → stars

Inventory of "stuff" making up our galaxy

INVENTORY OF MILKY WAY

Stars

1. STARS — FEW HUNDRED BILLION, $\approx 10^{11} M_\odot$
   - BULGE — MEDIUM TO OLD, "METAL POOR"
   - DISK — YOUNG, "METAL RICH" INCLUDES OPEN CLUSTERS, OB ASSOCIATIONS
   - HALO — OLDEST, METAL POOR. INCLUDES GLOBULAR CLUSTERS

Gas

2. GAS — 10% MASS OF STARS
   - MOSTLY IN DISK — INTERSTELLAR MEDIUM
     - A. VERY COLD GAS IN THIN SHEET. SITE OF STAR FORMATION (MOLECULAR CLOUDS)
     - B. WARM ATOMIC AND IONIZED H CLOUDS. EMISSION NEBULAE (BRIGHT NEBULAE)
     - C. HOT GAS. HEATED BY STELLAR WINDS, SUPERNOVAE
   - HALO — VERY HOT GAS BLOWING OUT OF GALAXY

Dust

3. DUST — 1% MASS OF GAS, 0.1% MASS OF STARS. MOSTLY IN CLOUDS IN DISK

+ "dark matter"

Clicker reading Q: Where are we?

A.

- *The Sun's location in the Milky Way is _____.*
- *A.* in galactic disk, about halfway between center and outer edge of disk
- *B.* in halo of galaxy, about 28,000 light years above galactic disk
- *C.* at very outer edge of galactic disk
- *D.* very near the galactic center

Ingredients of Interstellar Medium (ISM) (stuff between the stars)

COMPONENTS OF INTERSTELLAR MEDIUM

1. GIANT MOLECULAR CLOUDS ~ $10^5 M_\odot$
   - SITES OF INTENSE STAR FORMATION
   - NEARLY 50 MOLECULES DISCOVERED BY EMISSION LINES OBSERVED IN RADIO
     COMBINATIONS OF H, C, N, O FORM MOLECULES (AS MANY AS 11 ATOMS!)
     → AMMONIA, WATER, FORMALDEHYDE, METHYL & ETHYL ALCOHOL, CYANOGEN, CARBON MONOXIDE (CO) ...
     CO IMPORTANT FOR DOPPLER MAPPING OF CLOUDS WITH RADIO OBSERVATIONS

Very cold gas: star birth

2. DIFFUSE CLOUDS OF GAS (AND SOME DUST)
   HI REGIONS: CLOUDS OF COOL, NEUTRAL HYDROGEN ATOMS (REFLECTION NEBULAE)
   21 cm RADIO EMISSION

Cool gas: neutral H

   HII REGIONS (EMISSION NEBULAE): GLOWING, IONIZED HYDROGEN SURROUNDING YOUNG HOT STARS (O & B ASSOCIATIONS)

Hot H

More stuff in ISM inventory

INTERSTELLAR MEDIUM ...

3. HOT INTERCLOUD GAS > 10^6 K
   - HEATED BY SUPERNOVAE, STELLAR WINDS
   - FILLS HALO, GALACTIC WIND?
   - HIGHLY IONIZED GAS, NO DUST
     EMITS X-RAYS, YIELDS UV EMISSION ...
     LIKE OXYGEN VI (OXYGEN STRIPPED OF 5 ELECTRONS!)

Really hot gas

4. COSMIC RAYS
   VERY ENERGETIC ATOMIC NUCLEI (PARTICLES)

5. INTERSTELLAR DUST
   NOT MUCH BY MASS, BUT ....
   REDDENS STARLIGHT, ABSORBS SOME OF IT, POLARIZES THE LIGHT

Dust

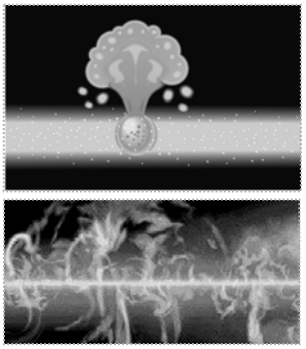
Now let us look at them in turn ....

ISM Contents: some stuff is HOT

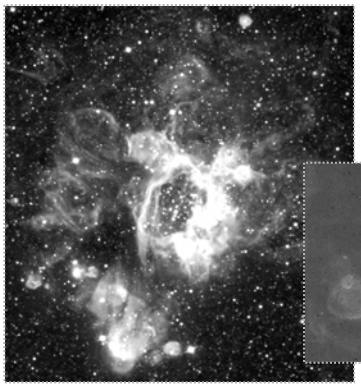
- *Bubbles of hot gas blown out by SUPERNOVAE*
- *T = million degree K*
- *Mixing with rest of galactic gas → enrichment with heavy elements*

Super-bubbles & Fountains

- *Supernovae can burst hot gas even out of the galaxy!*
- *"Enriches" gas between galaxies*
- *Some will rain back down and mix into galaxy*



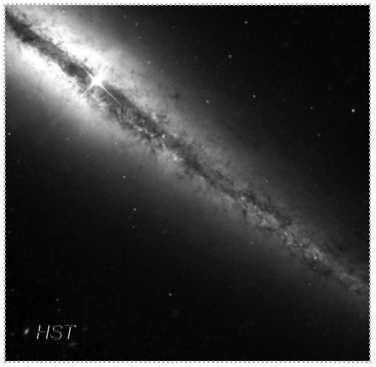
Artists' conceptions!



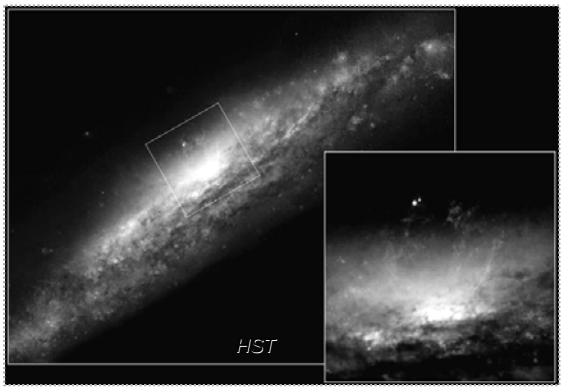
Super-bubbles in Large Magellanic Cloud (LMC) (nearby galaxy)

Edge-on view of spiral galaxy NGC 4013

- *Dust/gas in disk obscures light*
- *Plumes and fuzz sticking out are "fountains" & "superbubbles" from supernovae*

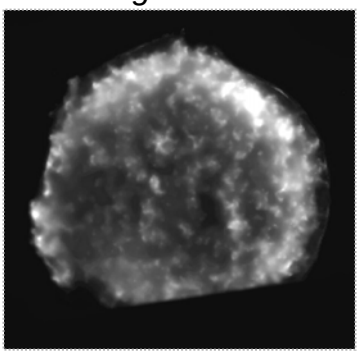


Super-bubbles in spiral galaxy NGC 3079



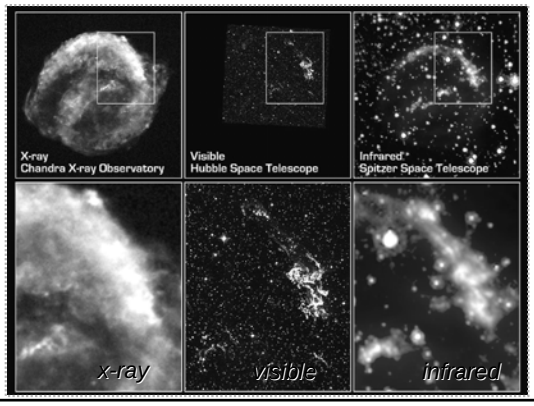
Fast electrons & magnetic fields

- *Synchrotron emission from SNR*
- *X-ray and radio*
- *Traces very hot gas bubbles (SNR)*

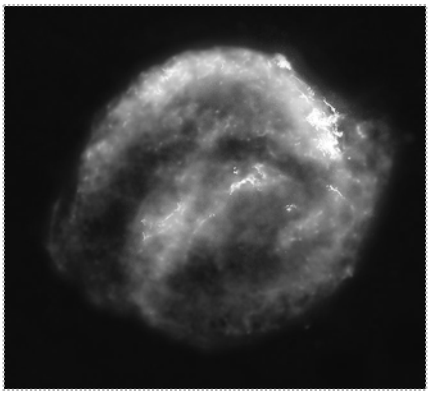


Chandra X-ray image of Tycho Brahe 1572 supernova remnant

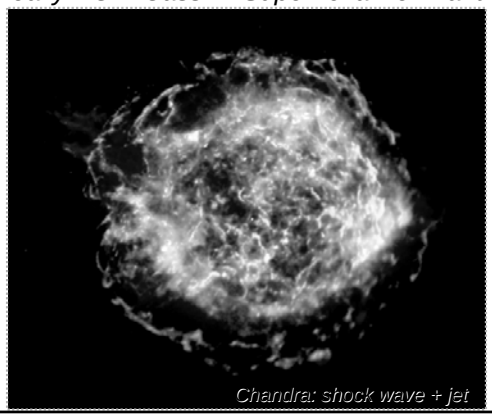
Kepler's SNR (1604) latest SN in MW



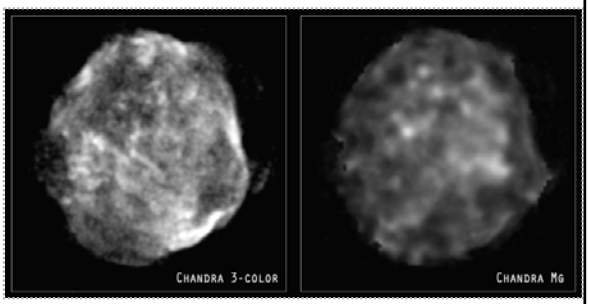
Kepler SNR (1604) Chandra X-ray



Really HOT: Cass A Supernova Remnant



Supernova Remnant N49B in LMC



Chandra x-ray images reveal ~one solar mass of magnesium blasted into space by SN

Clicker – stars and "heavy metals"

- *The ages of stars suggest that the bulge and halo of the Milky Way formed before many of the stars in the disk. Which would you expect to have <u>more heavy metals</u> (higher metallicity)?*

B.

- *A.* Halo and bulge stars
- *B.* Disk stars
- *C.* No difference

- *B.* *<u>Disk stars</u> are continually forming out of gas that is more and more "polluted" by heavy metals.*
- *The OLD globular clusters <u>in the halo</u> were formed a long time ago before the galaxy was so polluted – they have very low "metallicities"*

Some stuff is <u>WARM</u>

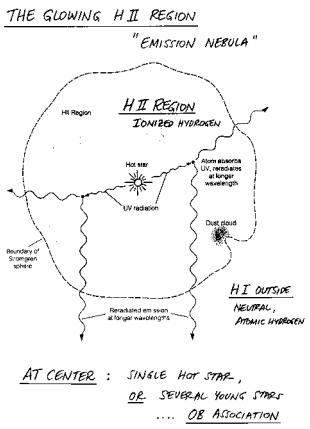
- *Gas & dust heated by stars*
- *<u>GAS</u> -- emission lines from hydrogen and other elements (ionization nebulae)*

T~ 10,000 K near hot young stars

T~ 100 K between star forming regions

ISM – hot gas: <u>Emission nebula</u> (H II region)

UV radiation from hot O or B star ionizes a big cavity

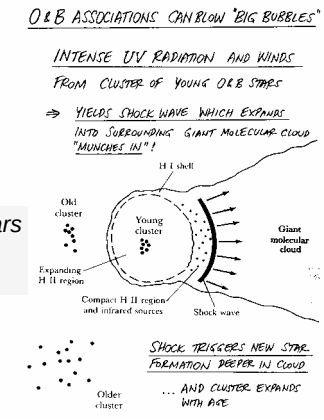


<u>Emission nebulae</u>
"O & B star associations"

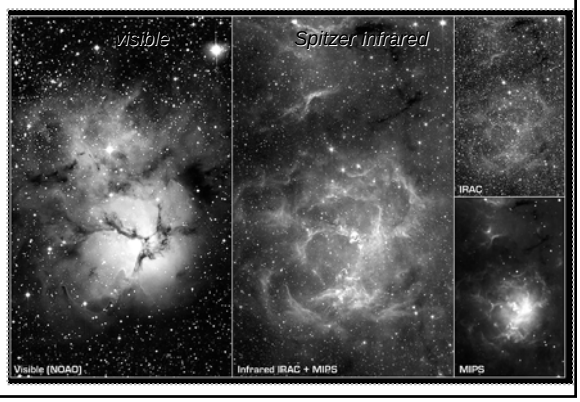
- *Emission lines from hydrogen and other ionized elements*
- *T~ 10,000 K near hot young stars*

O & B star associations

many cluster stars join in to blow "big bubbles"

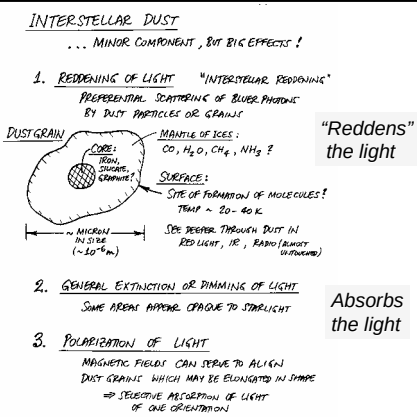


Trifid emission nebula "O & B star associations"



ISM:

A little DUST goes a long way!



"Reddens" the light

Absorbs the light

SEMI-WARM stuff: dust

- *DUST: absorbs visible and UV light*
- *Transparent to long wavelengths (red, IR, radio)*
- *Emits IR light*

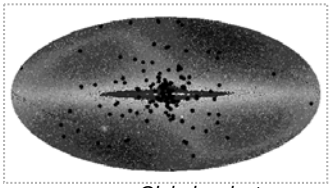
Dust+dark molecular clouds

Horsehead in close-up

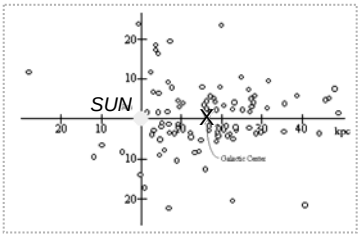
VLT

Where are we in MW?

Dust makes it hard to estimate distances (stars dimmed)



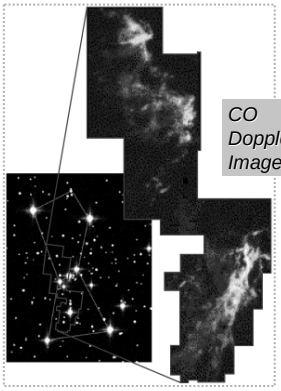
Globular clusters on COBE IR sky image



Shapley's (1920) distances to globular clusters: Sun at 18 kpc from center (twice too far!)

COLD stuff: dark clouds

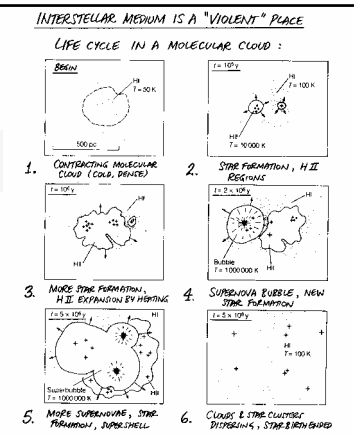
- *Molecular CLOUDS*
- *Dark, dusty, cold (10 - 30 K)*
- *Emit molecular emission lines in far IR, radio*
- *Orion image here in carbon monoxide (CO) -- colors are Doppler shifts*



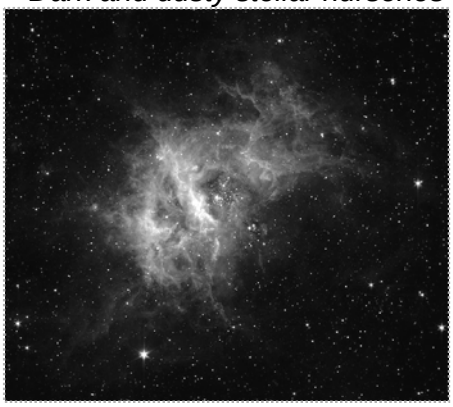
CO Doppler Images

ISM is a pretty violent place

"Life cycle" in a molecular cloud



Dark and dusty stellar nurseries



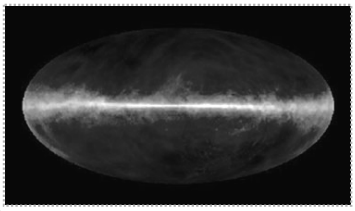
Nebula RCW 49 Stellar jewels Spitzer IR

Stellar nursery (Sharpless 140)

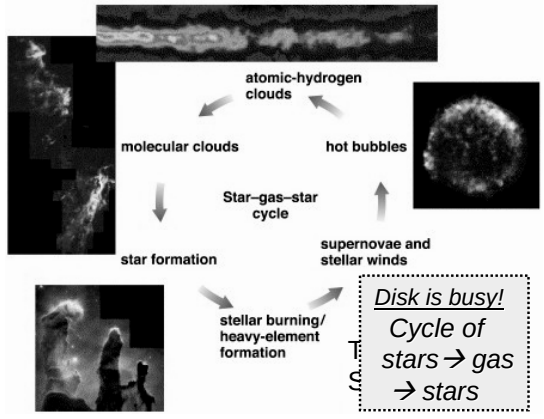
Spitzer IR image shows three deeply embedded O-type stars within dark dust cloud encasing them

COLD hydrogen throughout

- *Even the coldest hydrogen emits faint emission line in the RADIO*
- *Wavelength 21 cm*
- *Emission from flip of electron from spinup to spindown state*



All sky 21 cm radio mapping



Disk is busy!
Cycle of stars → gas → stars